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13. SUPPLEMENTARY NOTES

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14. ABSTRACT

20031001 201

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Determining Stress Sensor Requirements for a Health Monitoring System Using Finite Elements
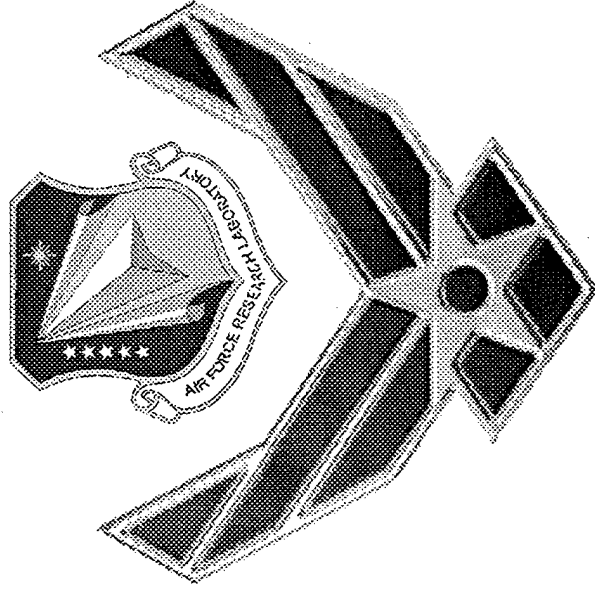
T. C. Miller
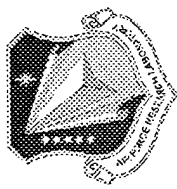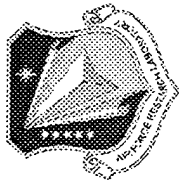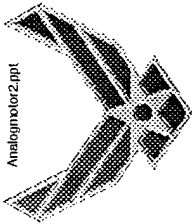
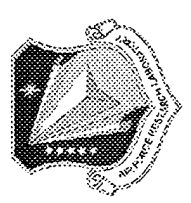Air Force Research Lab

Edwards AFB, CA
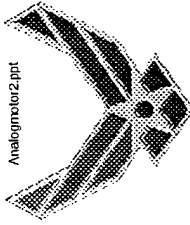
Outline of Presentation

- ## Introduction
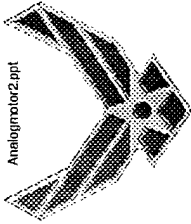
- ## Computational Modeling

- ## How FEA Results Are Analyzed

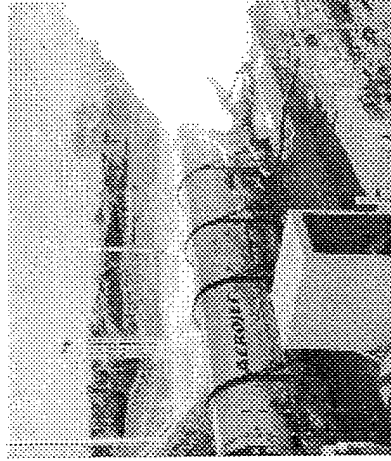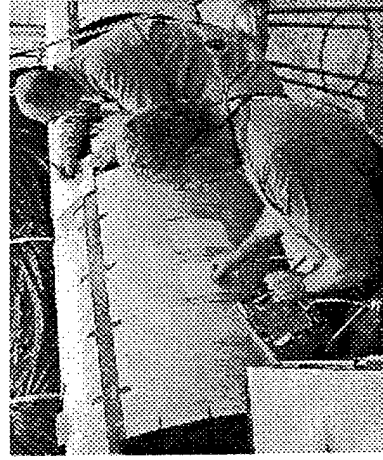- ## Summary and Main Points

Introduction
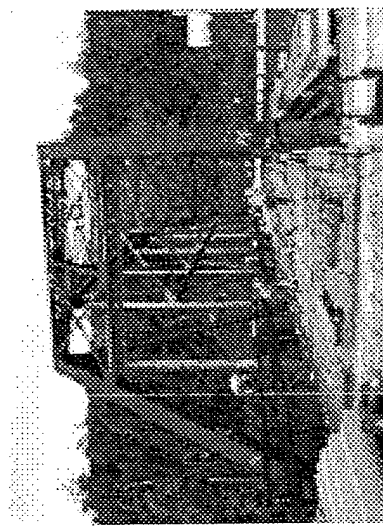
Analogmotor2.ppt

Motivation

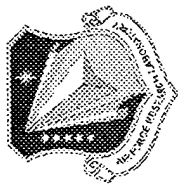## Consequences of Failure
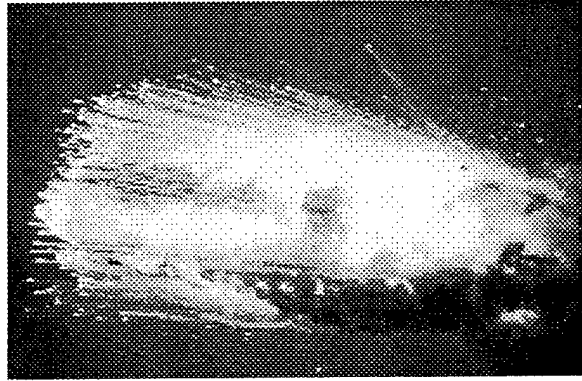
Ways to Ensure Reliability

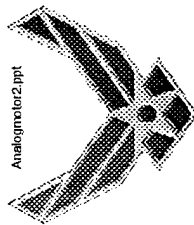**Live Testing**

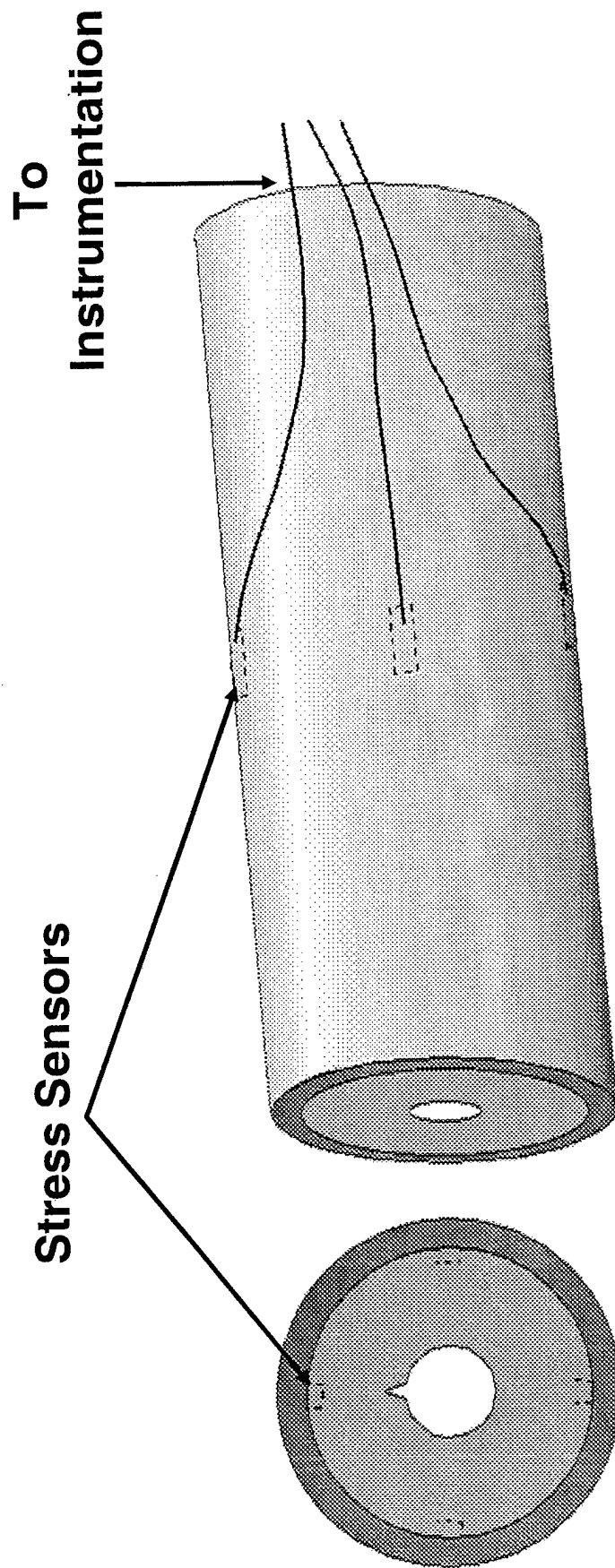**Nondestructive Evaluation**

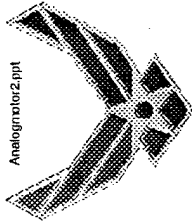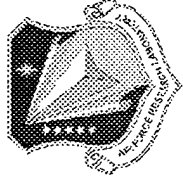**Health Monitoring**

Analogmotor2.ppt

Sensors On Inner Case Wall

To Instrumentation

Stress Sensors

Conventional Analysis For Hoop And Radial Stress

Pressure "P"

R_2

R_1

σ_{rr}

$\sigma_{\theta\theta}$
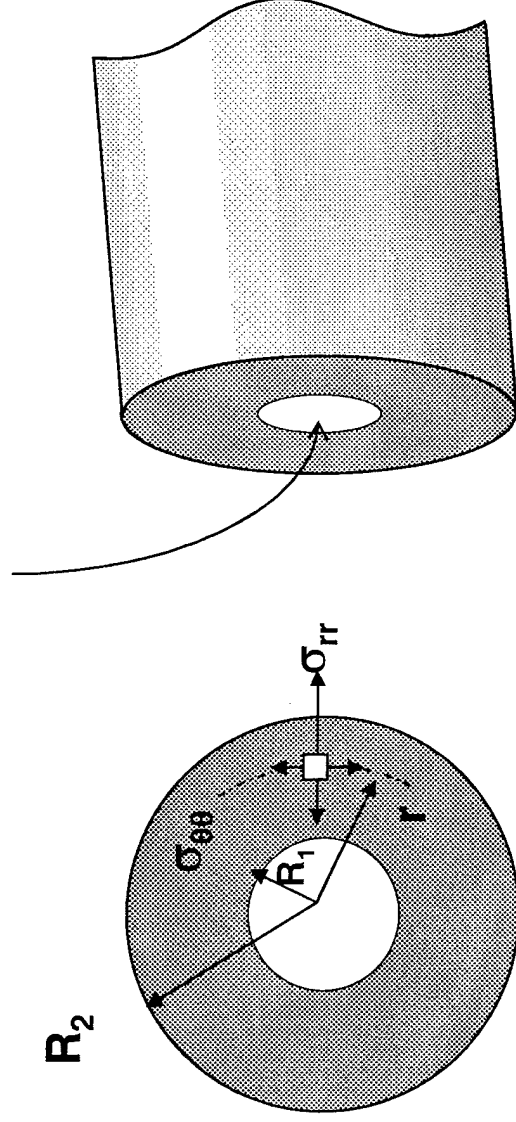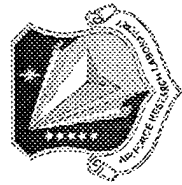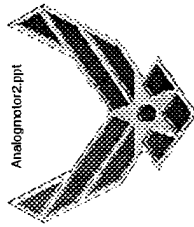
$$\sigma_{\theta\theta} = \frac{pR_1^2(R_2^2+r^2)}{r^2(R_2^2-R_1^2)}$$

$$\sigma_{rr} = \frac{-pR_1^2(R_2^2-r^2)}{r^2(R_2^2-R_1^2)}$$
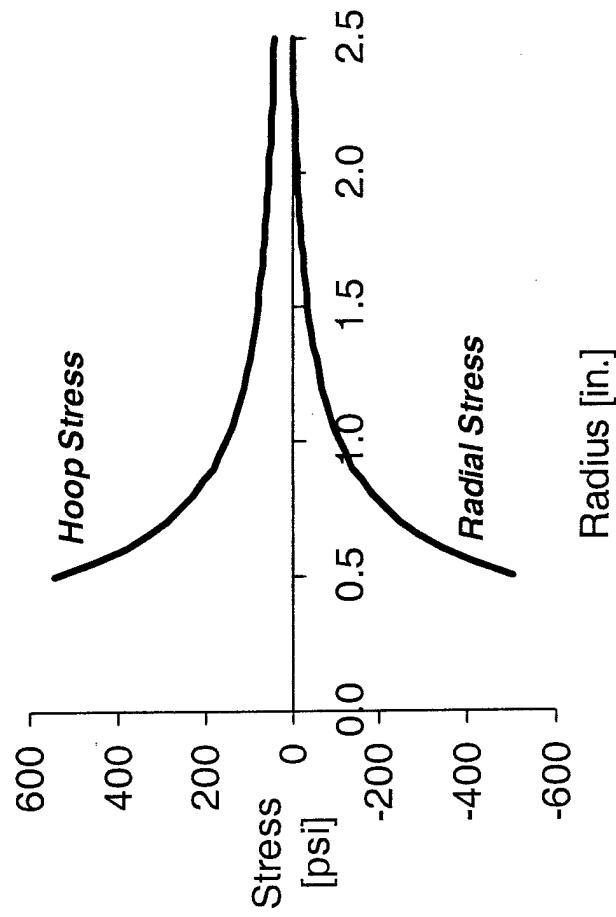
A conventional thick-walled pressure vessel analysis gives tensile hoop stresses but does not apply to solid rocket motors.
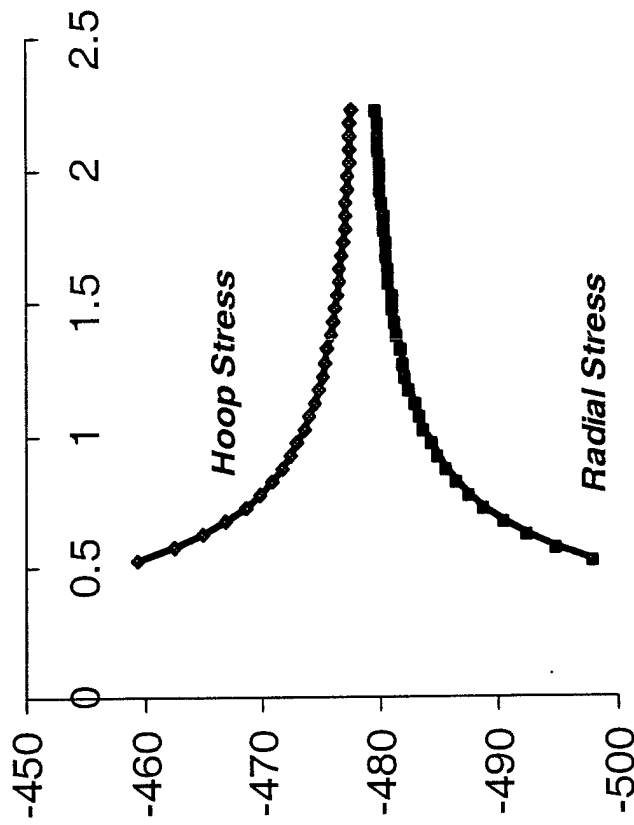
Analoginator2.ppt

Pressure Vessels And Solid Rocket Motors

Conventional Pressure Vessel Analysis

Hoop Stress

Radial Stress

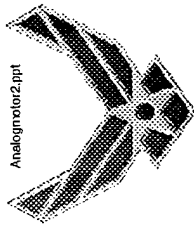Stress [psi]

Radius [in.]

SRM Pressure Vessel Analysis

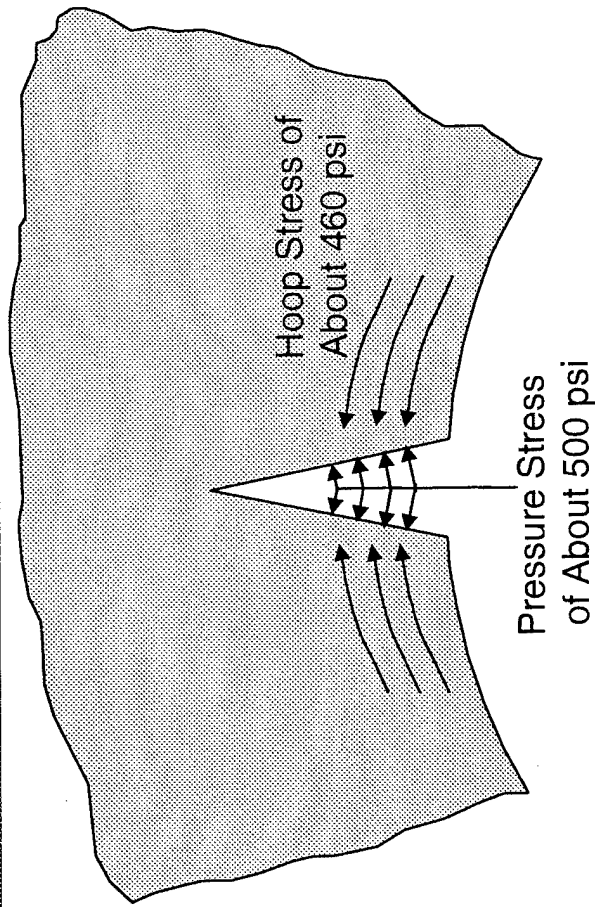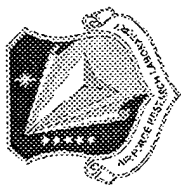Hoop Stress

Radial Stress

For this motor geometry and loading the stress sensor readings for an uncracked will be close to -500 psi.

Negative hoop stresses would close the crack if it weren't for the pressure loads on the crack faces.

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Competing Hoop And Pressure Stresses

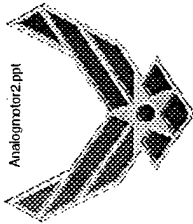Hoop Stress of About 460 psi

Pressure Stress of About 500 psi

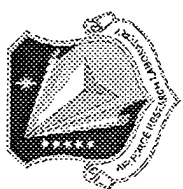$$K_I = (\sigma_{\theta\theta} + p)\sqrt{\pi a}\, f\!\left(\frac{a}{t}\right)$$

Relatively Weak Driving Force

The combination of negative hoop stress and pressurized crack faces results in substantially weaker "driving force" for fracture.

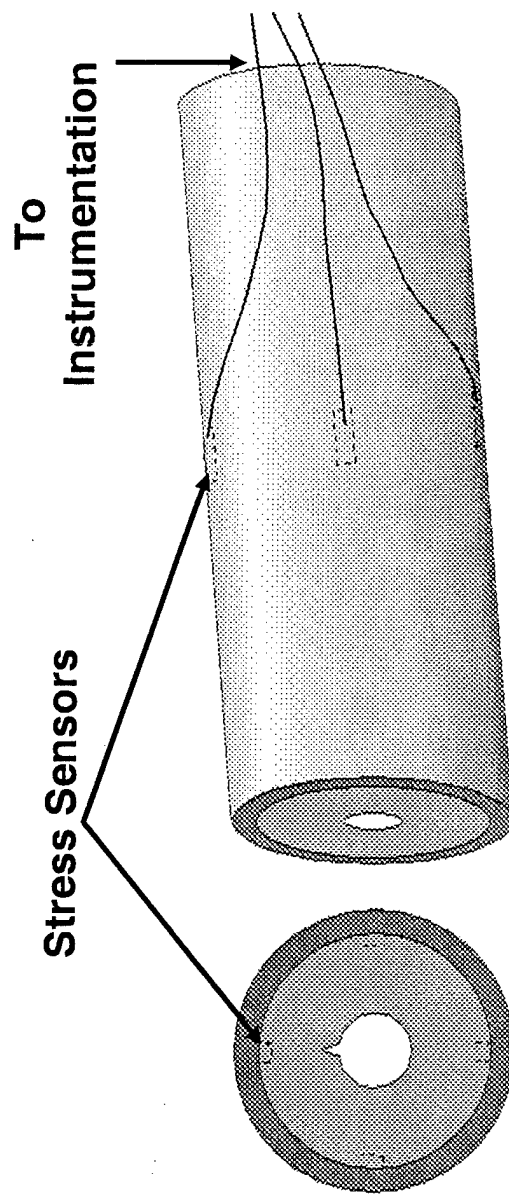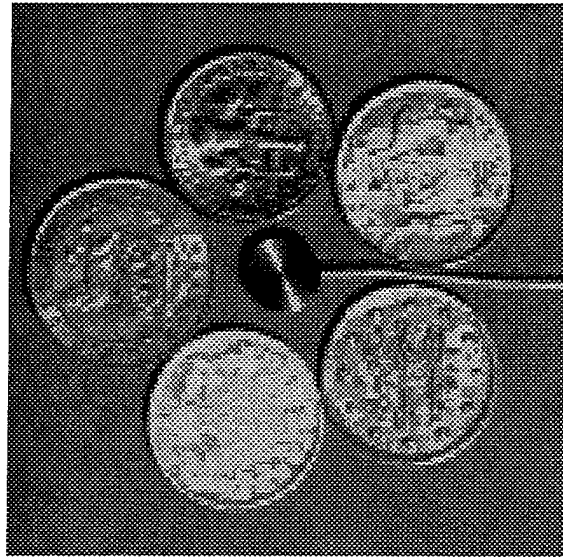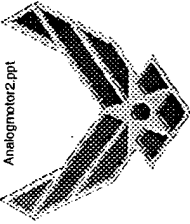Analogmotor2.ppt

Sensors On Inner Case Wall

How are the loads, geometry, and characteristics of the sensor system related?

Stress Sensors

To Instrumentation

Analogmotor2.ppt

# Parameters Affecting HMS Design
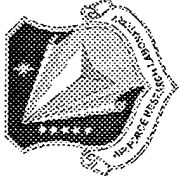
- Type and size of load

- Expected crack geometry

- **Requirement for minimum detectable crack size**

- **Number of sensors**

- **Required sensor sensitivity**

The relationship between some of the system parameters (minimum detectable crack size, required sensor precision, and the number of sensors used) can be found using analysis of FEA data.
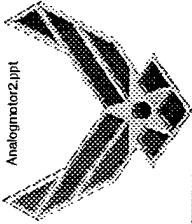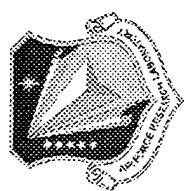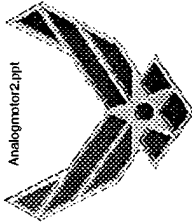
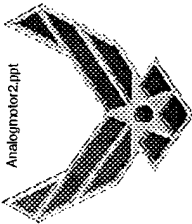# Using FEA As A Design Tool
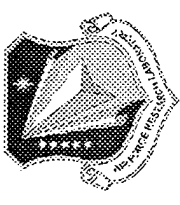
- General method is developed (can be applied to other situations, e.g., thermal loading)

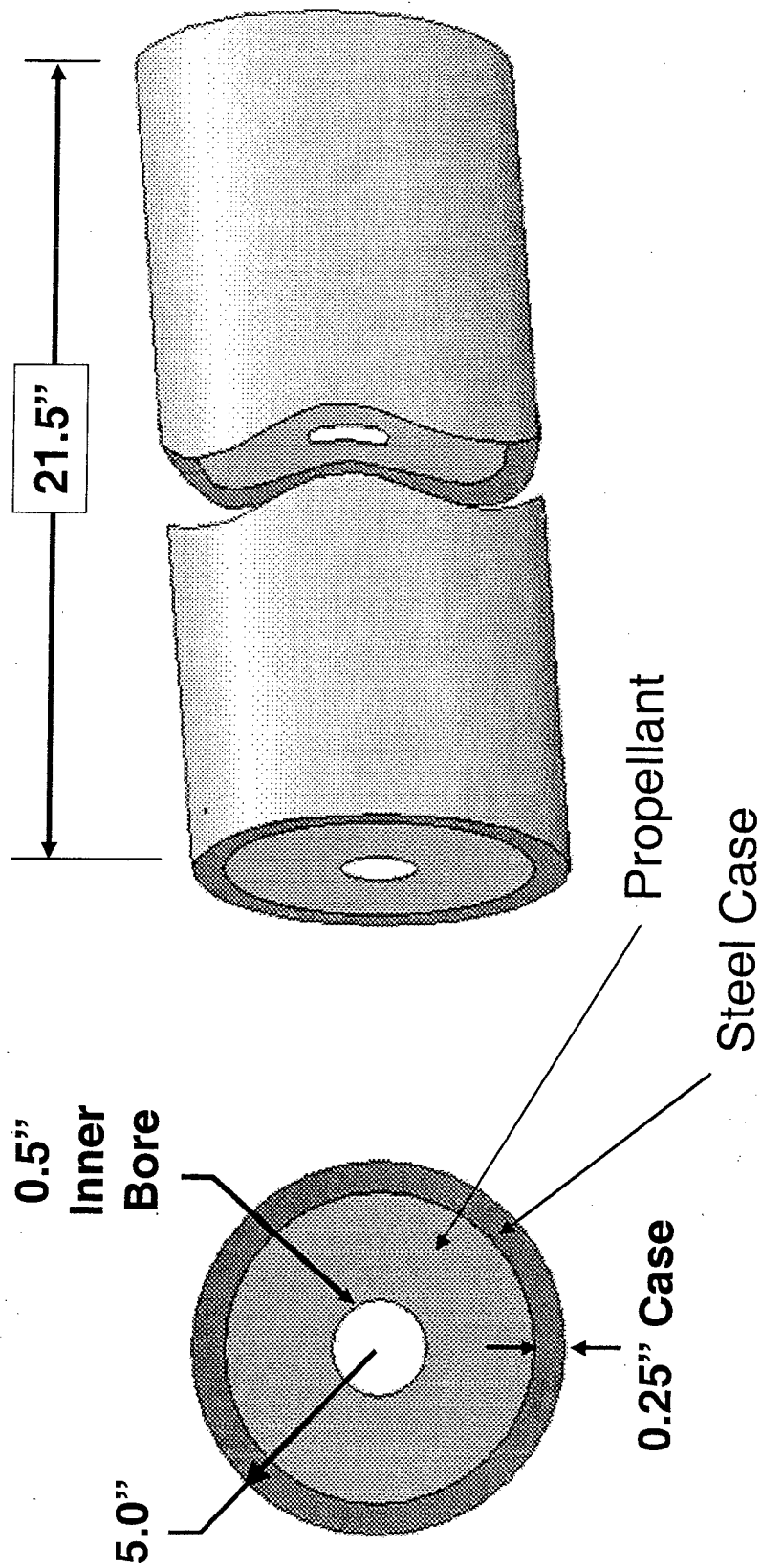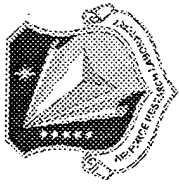- Specific relationship between variables is found
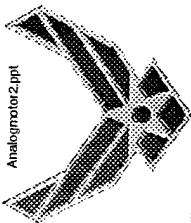
Computational Modeling

Motor Geometry

21.5"

0.5"
Inner
Bore

5.0"

Propellant

Steel Case

0.25" Case

Analogmotor2.ppt

Model Description –
Geometry And Loads

Case

Crack

Propellant

Pressure Loads

X

Y
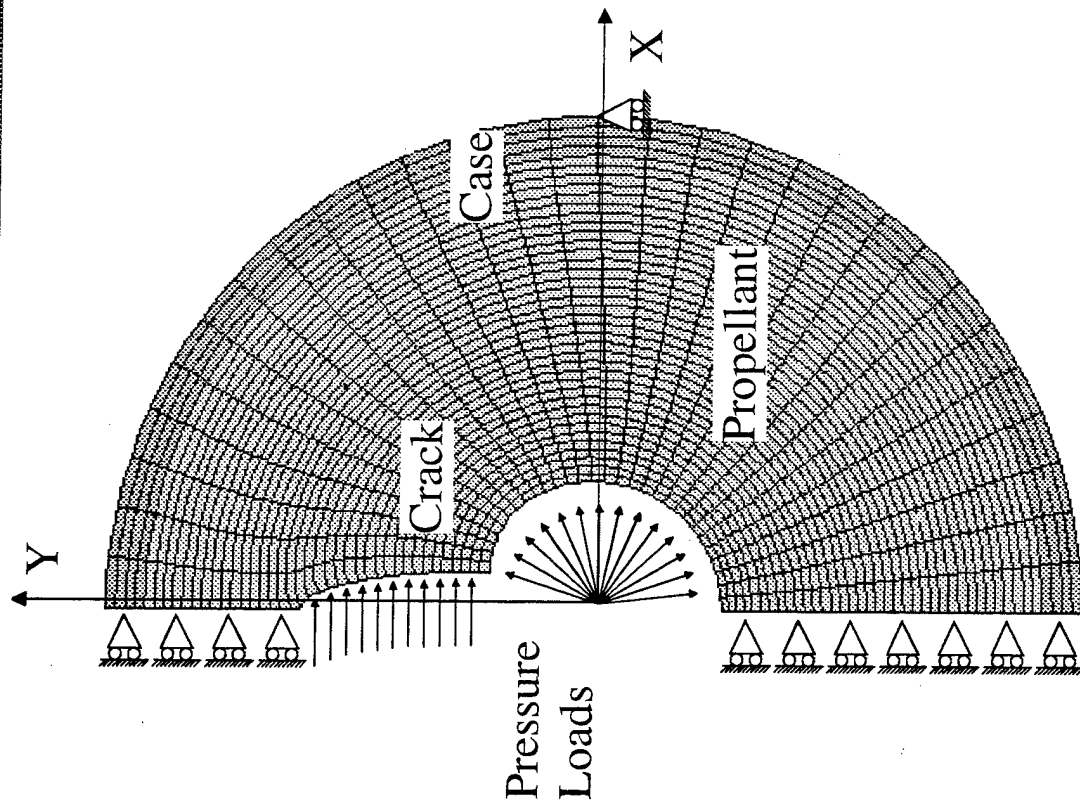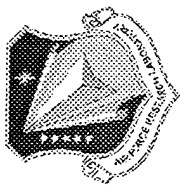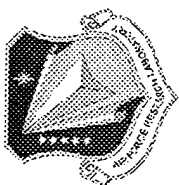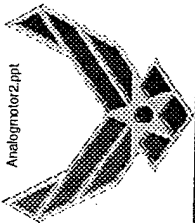
FEA Results and How They Are Used

Cracked And Uncracked Solid Rocket Motors

Uncracked Motor

Hoop Stress

Radial Stress

Radial Stress [psi]

479.7
481.4
483.1
484.8
486.5
488.1
489.8
491.5
493.2
494.9
496.6
498.3
499.9

Cracked And Uncracked Solid Rocket Motors

Cracked Motor

Near-Case-Wall Radial Stress Distribution for Uncracked Motor

Radial Stress [psi]

-479.7
-481.4
-483.1
-484.8
-486.5
-488.1
-489.8
-491.5
-493.2
-494.9
-496.6
-498.3
-499.9

Cracked And Uncracked Solid Rocket Motors

Radial Stress [psi]
-465
-468
-471
-474
-477
-480
-483
-486
-489
-492
-495
-498
-501

Cracked Motor

Near-Case-Wall Radial Stress Distribution for Uncracked Motor

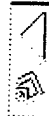*Near-Case-Wall Radial Distribution for one-inch crack*

θ [deg.]
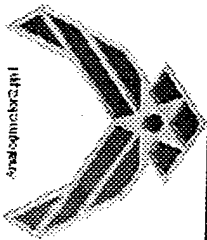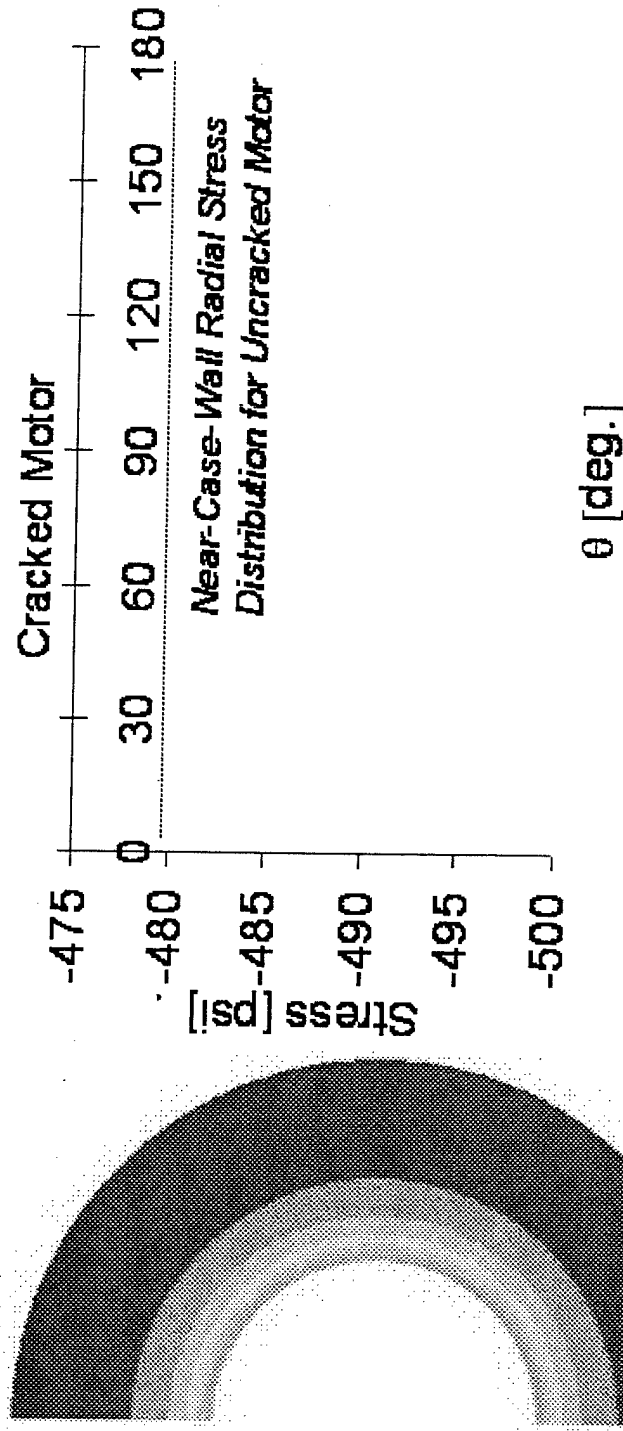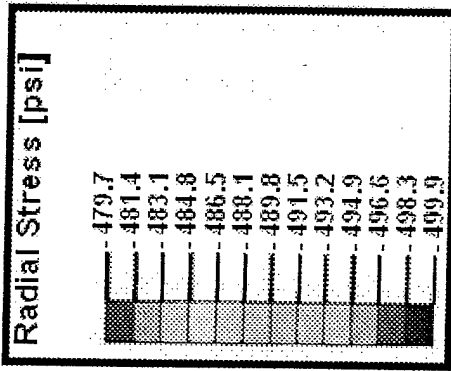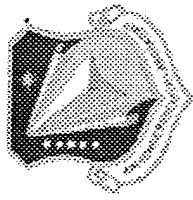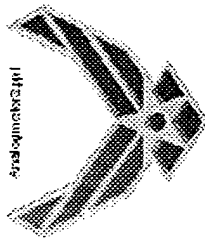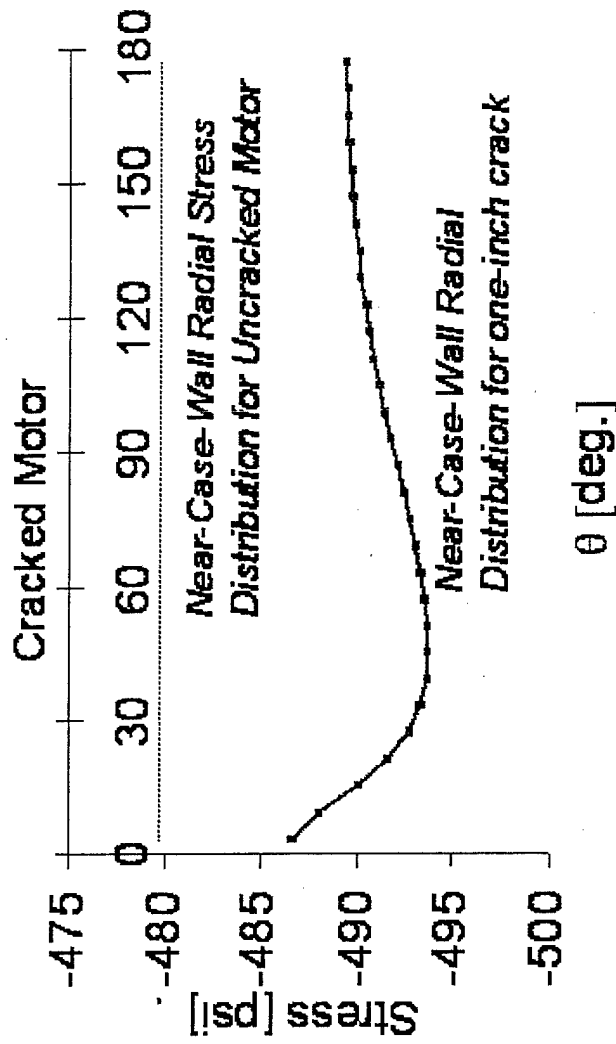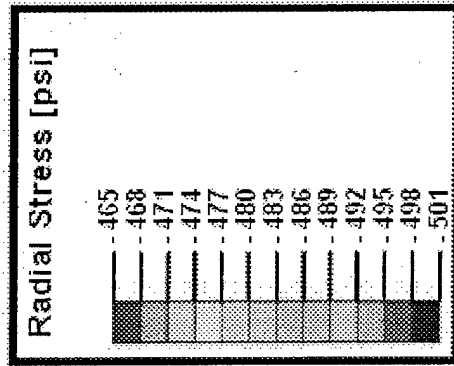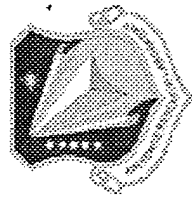
The uncracked motor has "baseline stresses," but the presence of a crack causes deviations that vary with orientation.
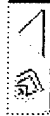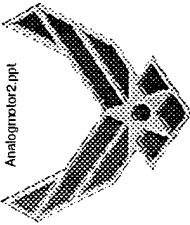
Change In Stresses Near Case Wall Is Felt By Sensors
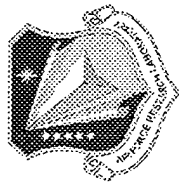
Change in Radial Stress Components Near Case Wall for Analog Motor at 500 psi
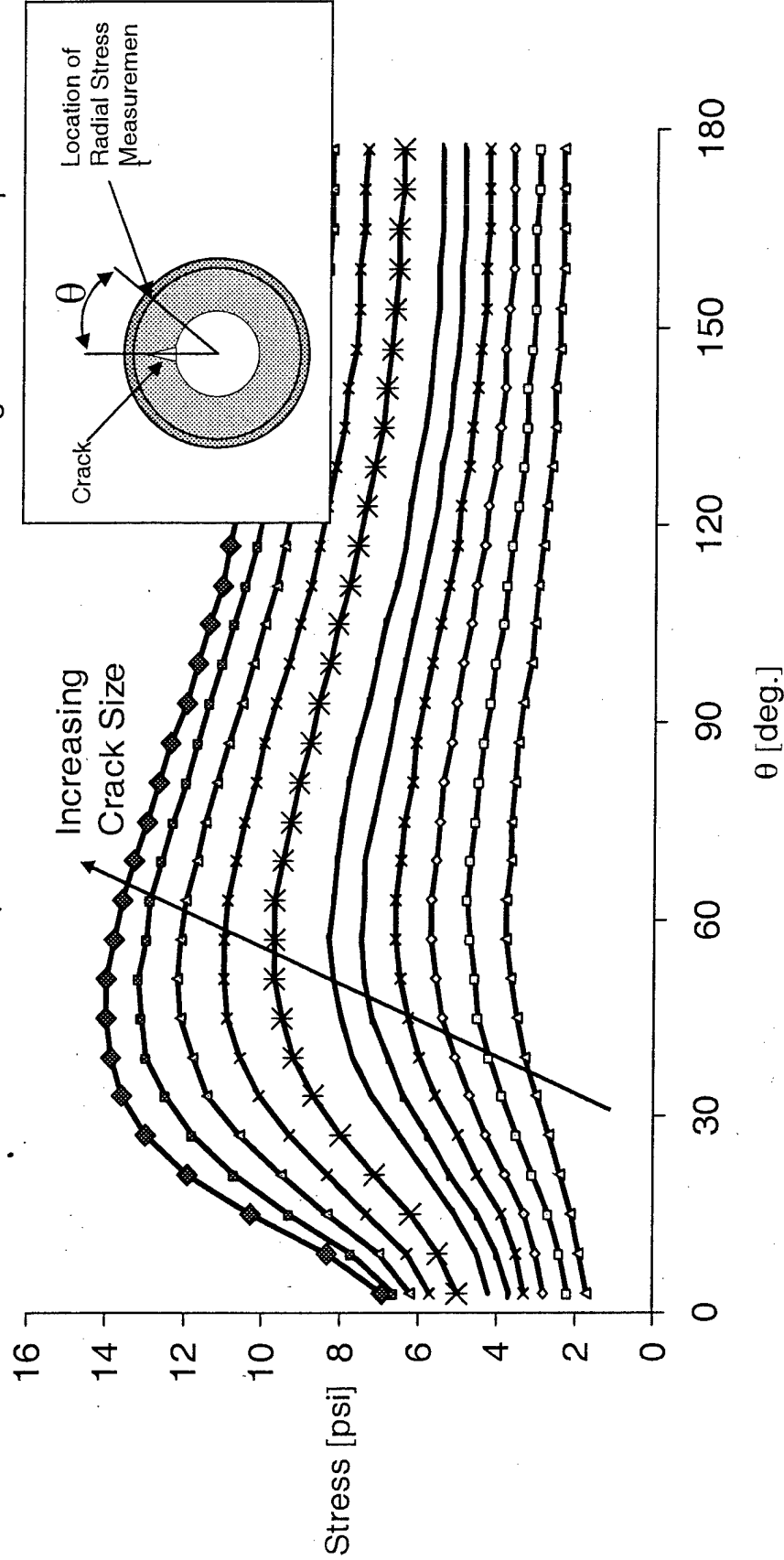
The difference between the baseline stresses and the case wall stresses in a cracked motor may or may not be detectable.
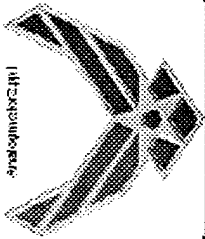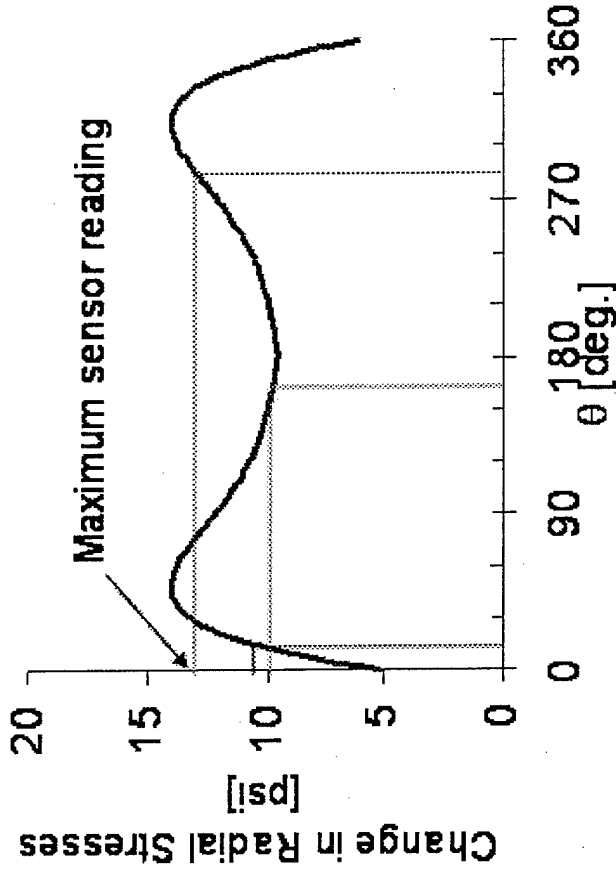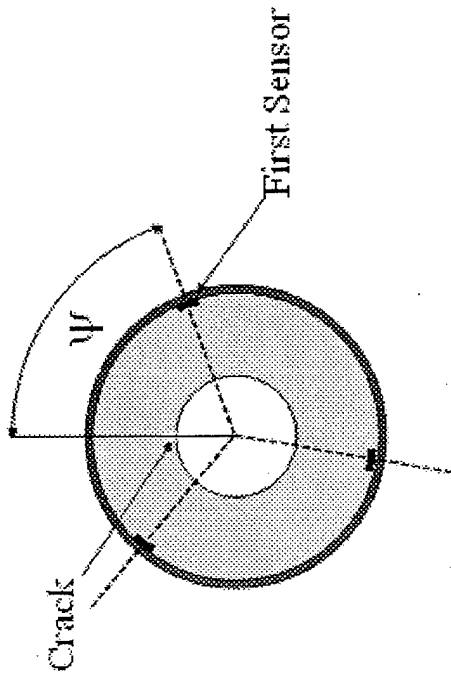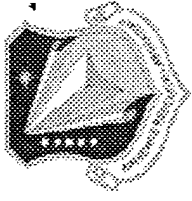
How FEA Results Are Analyzed

How FEA Results Are Analyzed

In the worst case scenario, the sensors will be aligned so that the <u>maximum</u> of the three sensor readings will be at a <u>minimum</u>. Detection of the crack may or may not be possible.
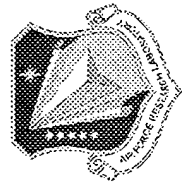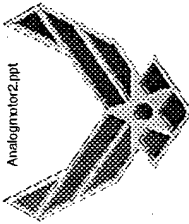
Results Relating Number Of Sensors, Sensor Precision, And Minimum Detectable Crack Size
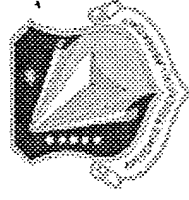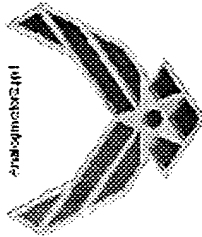
Analogmotor2.ppt

Number of Sensors
- 3
- 4
- 5
- 6
- 8

Required Sensor Precision [psi]

16 — 14 — 12 — 10 — 8 — 6 — 4 — 2 — 0

0.25   0.50   0.75   1.00

Minimum Detectable Crack Size [in.]

For this motor geometry and loading, the number of sensors recommended is four and the sensor sensitivity required depends on the crack size (quantified by the chart).
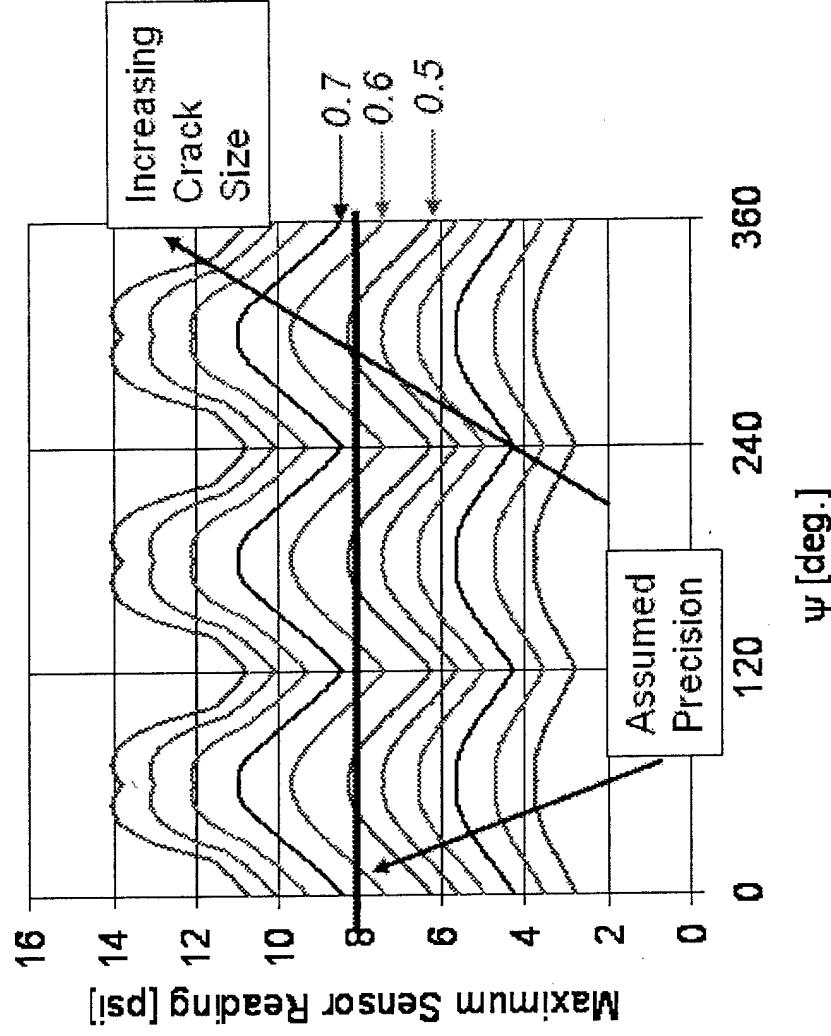
Approved for public release; distribution unlimited
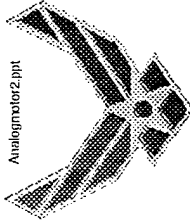
Summary and Main Points
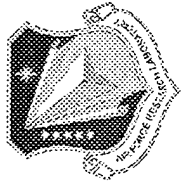
A conventional thick-walled pressure vessel analysis gives tensile hoop stresses but does not apply to solid rocket motors.

Negative hoop stresses would close the crack if it weren't for the pressure loads on the crack faces. The combination of negative hoop stress and pressurized crack faces results in substantially weaker "driving force" for fracture.

The relationship between some of the system parameters (minimum detectable crack size, required sensor precision, and the number of sensors used) can be found using analysis of FEA data.

The uncracked motor has "baseline stresses," but the presence of a crack causes deviations that vary with orientation. The difference between the baseline stresses and the case wall stresses in a cracked motor may or may not be detectable.

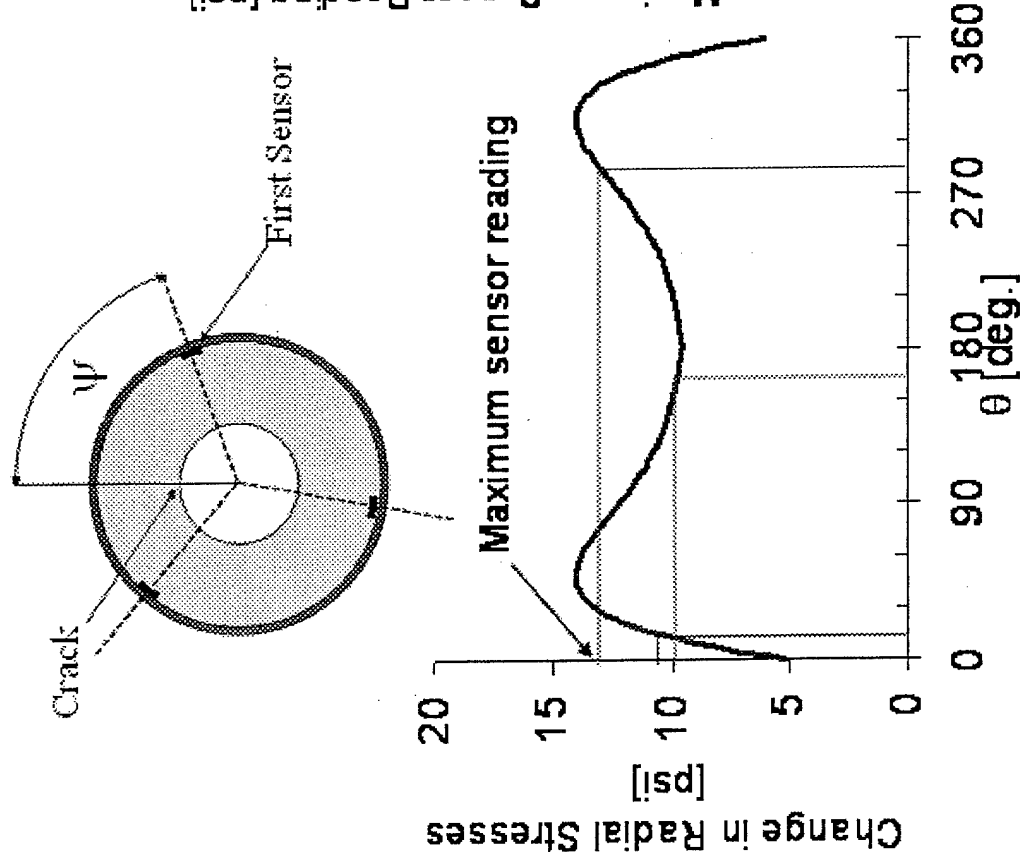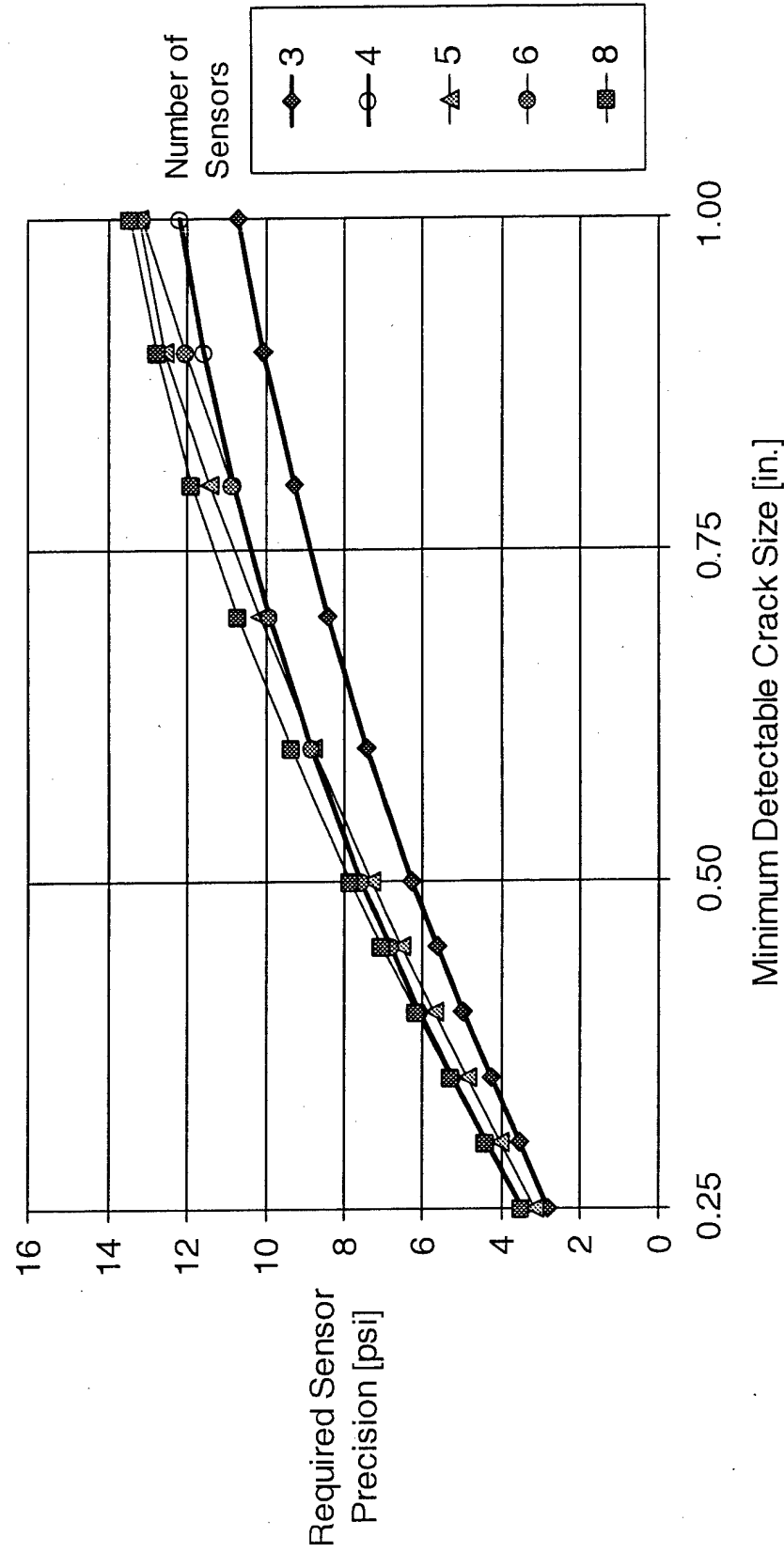In the worst case scenario, the sensors will be aligned so that the maximum of the three sensor readings will be at a minimum. Detection of the crack may or may not be possible.

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